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California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response

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Abstract

The invasive marine alga *Caulerpa taxifolia* was discovered June 12, 2000, in California at Agua Hedionda Lagoon. Due to a 15-year history of spread in the Mediterranean Sea, *C. taxifolia* had already been placed on the US Federal Noxious Weed list in 1999. Awareness of this threat greatly facilitated consensus building and setting clear eradication goals among a large number of state, federal and local agencies as well as private groups and non-governmental organizations (NGOs) that became the 'Southern California Caulerpa Action Team' (SCCAT). Field containment and treatments began 17 days after the discovery due to: (1) timely identification and notification of the infestation; (2) the proactive staff of the San Diego Regional Water Quality Control Board who deemed this invasion tantamount to an 'oil spill', thus freeing up emergency funding; (3) the mobilization of diver crews already working at the site. Three well-integrated components of this rapid response have resulted in an effective eradication program: (a) expertise and knowledge on the biology of *C. taxifolia*; (b) knowledge on the uses, 'ownership' and characteristics of the infested site; (c) knowledge and experience in the implementation of aquatic plant eradication. Together, with the requisite resources (approximately $US1.2 million per year), this approach has resulted in containment, treatment and excellent progress toward eradication of *C. taxifolia*. Successful rapid response to other aquatic invasive species will require similar readiness to act, and immediate access to adequate funding.

Introduction

In order to consider the need for, and optimal components of, effective responses to newly discovered invasive species, it is instructive to view these incursions within the context of more generic environmental or health emergencies. The US and indeed most of the developed countries have well-defined systems for responding to the most common types of catastrophies, such as fire, flood, earthquakes or disease outbreaks. The systems are comprised of early warning devices or networks, and equally important, the physical and human resources needed to react quickly. Societies have generally recognized the huge social and economic costs of delays in response to these untoward, but inevitable occurrences. Unfortunately, there is neither an adequate awareness of the costs, nor are the systems in place to mount a similar action for the analogous disruptions caused by problematic invasive species, particularly in the marine and freshwater environments. The rampant spread of many invasive plants attests to the lack of response capacity

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(Mullin et al. 2000). A clear example is the reaction to the discovery of northern pike *(Esox lucius*) in Lake Davis, CA during the early 1990s (Lee 2001). The response by the California Department of Fish and Game (CDFG), which consisted of pisciside (rotenone) applications in 1997, resulted in rancorous public objections and litigation. It was not until 1999, nearly four years after the threat was clearly understood by CDFG scientists, that a stakeholder group was formed and a consensus-driven plan was developed (California Department of Fish and Game 2000). Northern pike are still present, but now there is far more unanimity of purpose and a more cooperative atmosphere that can facilitate steps needed to reduce the threat from Northern Pike. However, the costs of delays, in part resulting from inadequate approaches for rapid response, can be measured in years and more than $9 million in settlement fees (Goedde 1998).

California's recent success in thwarting (at least for now) the introduction of *C. taxifolia*, a marine alga, has revealed both conceptual and practical approaches that are useful as a model for constructive and effective response to incursions of other invasive species. Over the past few years, there have been other published proposals in the US for rapid responses to invasive species (e.g., National Invasive Species Council 2003; FICMNEW 2003; Western Regional Panel 2003). There have also been several state plans developed during the past 5 years to address the threats to aquatic resources posed by a variety of invasive freshwater and marine organisms, including 13 plans approved at this time by the federal Aquatic Nuisance Species Task Force (ANSTF). These plans also contain rapid response strategies. Target species range from microscopic, ballast water-borne organisms to large vertebrates such as the northern pike and snakehead fish (*Channa argus*), as well as a variety of freshwater and marine plants and invertebrates. However, with a very few exceptions, such as the 25 year-old Hydrilla Eradication Program in California (California Department of Food and Agriculture 2002), the plans at this time are analogous to having a conceptual design for a fire department, but with no fire station, no on-call fire fighters, no pool of effective fire-fighting equipment, no mandate or authorization to fight fires, and no hands-on training for fire-fighters. As a result, reactions today to new introductions of invasive species are usually far too late, poorly coordinated and often provoke negative reactions from stakeholders who do not understand the threats, costs, risks, and benefits of immediate action as compared to the risks of not responding quickly, decisively and effectively. The public, in short, has a clear grasp of threats from fires and floods, but only the most vague understanding of how invasive species affect their lives. The state plans mentioned above all have public education/outreach components, but realistically, creating an awareness similar to that for fire prevention and fire-hazards will probably take a generation. What can be done now to counter the establishment of new invasive species? What can we learn from the limited examples of successful responses? The recent introduction of the marine alga *C. taxifolia* into a southern California lagoon, Agua Hedionda, and a small embayment called Huntington Harbour provides some answers. The following is a synopsis of the development of the eradication actions, and recommendations for applying lessons learned from the project to the broader concern of invasive species intervention. Other brief accounts of the early phases and various aspects of this project have been reported elsewhere (Anderson 2001, 2002; Anderson and Keppner 2001; Jousson et al. 2001; Williams and Grosholz 2002).

C. taxifolia invasion in the US

Early detection – a fortuitous awareness

The history and almost 20-year spread of *C. taxifolia* in the Mediterranean Sea is well described (Meinesz 1999, 2001). However, until the discovery in California in 2000, no other populations had been documented in the western hemisphere. Agua Hedionda Lagoon is a small (ca. 150 ha total) estuary located about 50 km north of San Diego, CA (Figure 1). It is comprised of three sections: the outer lagoon (adjacent to, and connected with, the Pacific Ocean), the middle lagoon and the inner lagoon; it was in the latter section that *C. taxifolia* was found. The overall lagoon is used for a variety

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COLOUR FIG.

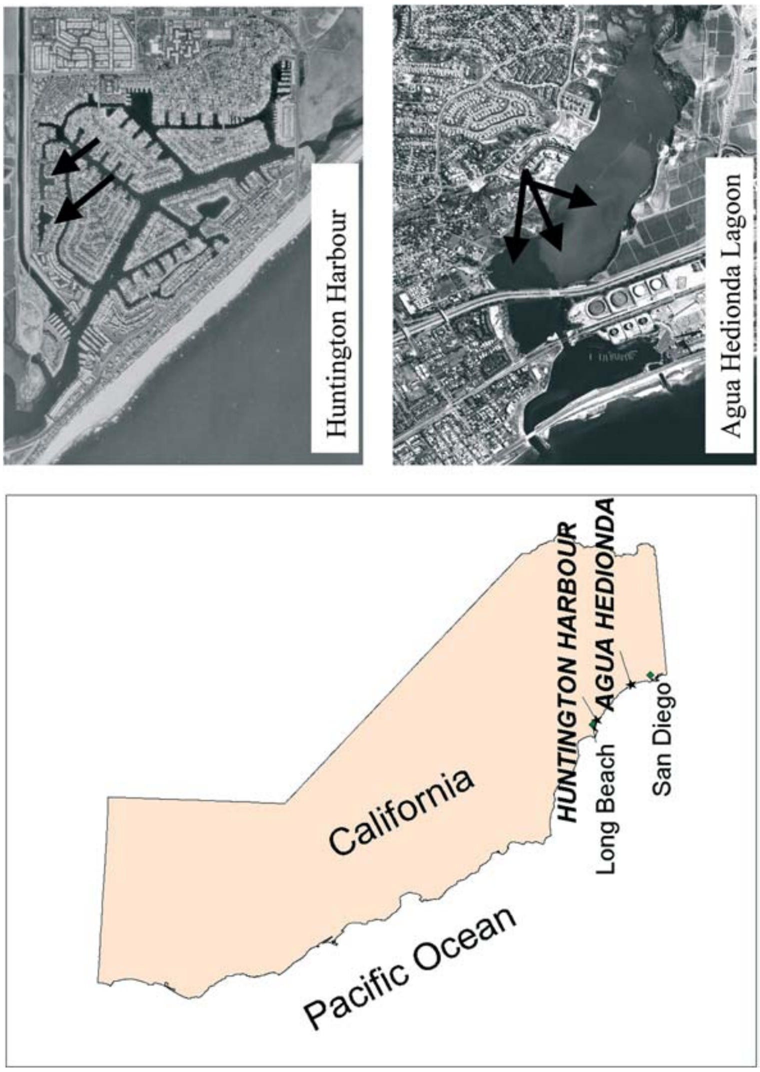

Figure 1. Locations of *C. taxifolia* infestations in California. Arrows show specific areas within sites. Huntington Harbour (upper right); Agua Hedionda Lagoon (lower right).

of public and private activities: recreation (fishing, paddling, water skiing, and wave boarding), power production (i.e., cooling water), aquaculture, and personal watercraft ('jet ski') rentals. Most recreational activities occur in the inner lagoon and therefore subsequent actions to eradicate this invasive species directly affected a variety of stakeholders, including many homeowners adjacent to the lagoon. The Huntington Harbour site occupies about 4 ha and consists primarily of two small, relatively isolated basins surrounded by houses. It is connected via large pipes to the outer harbor area, which is in turn connected to the ocean.

At the time *C. taxifolia* was discovered in June, 2000, a small team of SCUBA divers was documenting locations and status of native eelgrass beds (*Zostera marina*) as part of contract work for a power plant. Importantly, the dive-team leader recognized that the *C. taxifolia* colony was not part of the normal flora, and quickly notified the California Department of Food and Agriculture staff within the Pest Detection and Exclusion Branch, who then made

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contacts with those scientists and managers involved with aquatic invasive species control and eradication (Woodfield 2000, personal comm.) Specimens of the plant were sent immediately to specialists who could confirm the identity of the species. These critically important steps were taken within 24–72 h after the discovery. Later, more detailed genomic analysis confirmed that this population was identical to the plants that had spread in the Mediterranean areas (Jousson et al. 2001).

Agency and 'non-agency' responses

Within one week after the species was identified, representatives from several California state agencies, federal agencies, and a few key local stakeholders met to assess the threat. In subsequent meetings, representation expanded to include specialists in phycology. At this juncture, formal options for various actions were discussed, and the group arrived at a consensus to eradicate *C. taxifolia*. During this period, several of the agency representatives inspected the site at Agua Hedionda Lagoon, a critically important step. Understanding the physical characteristics of the site, and its proximity to the open ocean and to recreational and other uses of this lagoon was essential in the overall successful development of an eradication plan. The fact that one concessionaire's activity was directly affected by proposed eradication operations (e.g., restriction of boat use), as well as the likelihood that the very activity of the customers (i.e., jet skiing and wave boarding) might spread the infestation, resulted in lengthy negotiations between these stakeholders and the Steering Committee of what has become known as the Southern California Caulerpa Action Team, or SCCAT. Discussions and negotiations on other 'passive' uses in the lagoon (e.g., fishing, non-motorized watercraft) were also begun, including informational public workshops that included the non-profit group Agua Hedionda Lagoon Foundation (AHLF) and other affected property owners.

This quick progression in the response first involved a few 'official agencies', but very soon included several public and private groups, which ultimately comprised SCCAT (see Appendix 1). Although without any formal jurisdiction, or direct funding, SCCAT has acted as an advisory lead consortium whose goal is to implement eradication plans, and to ensure the success of the eradication project through judicious, scientifically based monitoring and evaluation. Initially, monthly meetings, and more recently bimonthly meetings have been held for over 4 years. Currently, representatives from five agencies comprise the Steering Committee: California Department of Fish and Game, San Diego Regional Water Quality Control Board, Santa Ana Regional Water Quality Control board, NOAA-Fisheries, and US Department of Agriculture-Agricultural Research Service. Within SCCAT, there are separate committees that address public education, outreach, and technical issues. The Steering Committee has also worked directly with stakeholders to develop consensus-based use plans for Agua Hedionda Lagoon. Figure 2 shows the overall organization of SCCAT.

The success of SCCAT stems, in large part, from the personal commitment of the individuals who have brought their varied experience, expertise, and the support of their respective agencies, or private affiliations to bear on this problem. This eradication project was not, however, without early birthing pains. During initial evaluations of the threat from *C. taxifolia* and discussions of options for response, opinions differed at both the technical level as well as the sociological level. It is worth noting that the June

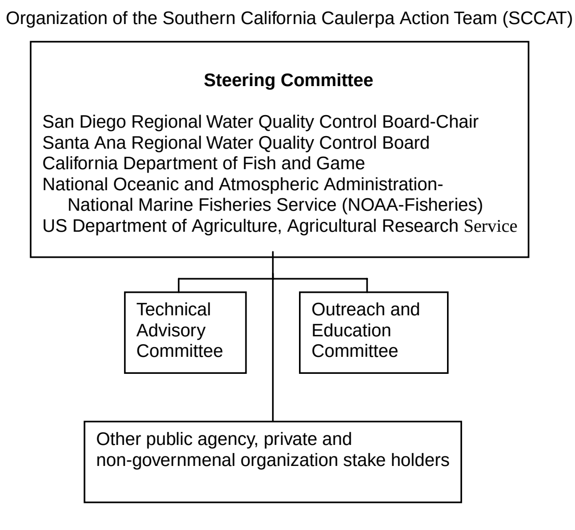

Figure 2. Organizational chart for the SCCAT.

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2000 infestation was the first known for *C. taxifolia* in the western hemisphere, and that there was no successful example of eradicating a marine alga in the US Legitimate and important questions were raised: Can this plant be eradicated? Should research be conducted for a while before eradication is attempted? What is the potential for dispersal beyond the lagoon? Is it already off the California coast, but simply undetected? Unfortunately, documented experiences in the Mediterranean invasion did not bode well for successful eradication. And yet, experience with much larger infestations of *Hydrilla verticillata* in California canals and lakes strongly suggested it could be done, but only if action were immediate, effective and unwavering (California Department of Food and Agriculture 2002).

Other critical questions were raised: What, if any, recreational activity should be allowed in or near the infested area? Who has legal authority to restrict boating and other recreational activities? For that matter, who owns the lagoon? Taken together, these were difficult problems. The solution has been to strike a balance between actions deemed essential for the project (containment, treatment and monitoring), and modifications in public access to, and uses within, the lagoon.

Operational realities – what to do and how to fund it

Once the consensus to eradicate was clear, the next obvious questions were: How? By what methods? Who will actually do it? What will it cost? Who will pay? Within two weeks after discovery, discussions centered on feasibilities for containment, chemical control, various types of dredging, draining coupled with construction of temporary dams, and tarping. In fact, the probability of successful eradication was questioned periodically as various methods were evaluated from the standpoint of cost, potential non-target impacts, and projected efficacy. For example, there are no federally registered products for control of marine algae except boat bottom coatings (antifouling paints). Thus chemicals (algaecides) would require a special permit from the California Environmental Protection Agency, Department of Pesticide Registration (CalEPA/DPR). In tandem with these discussions, pilot efficacy testing was performed in small containers with several registered aquatic herbicides such as diquat, endothal, chelated copper, fluridone, and sodium hypochlorite (household bleach). Only bleach (5% sodium hypochlorite) resulted in obvious toxicity symptoms (i.e., chlorosis and eventual disintegration of tissues) with short exposures of a few hours. Consideration of other options, such as dredging, quickly revealed the enormous operational costs, associated disposal and treatment issues, and concerns for non-target species. Localized, diver-assisted dredging was tested in uninfested areas, but the unconsolidated nature of the lagoon sediments rapidly reduced visibility and made this option impractical.

As the constraints of other methods became clear, as well as the need to take action, SCCAT concluded that the best approach for both containment and treatment of the *C. taxifolia* colonies was construction of small polyvinyl chloride (pvc) frames that were to be placed over the plants and then covered with black 20 mil pvc sheeting. The sizes of the tarps ranged from 500 m^2 areas for the few large colonies initially discovered, to about 1 m^2 for small plants found in later surveys. The sides of the tarps were anchored and sealed to the bottom with gravel-filled bags. An overhang was provided between the edge of the colony and edge of the bagged area to ensure that a margin of uninfested area was also covered and treated (Figure 3). Initially, liquid sodium hypochlorite (ca. 12% stock solution) was injected into the tarped areas via ports in the pvc tarps fitted with caps. Smaller colonies were later covered with the pvc tarps without a frame, beneath which several 2.5 cm dia. solid chlorine-releasing tablets ('pucks') were placed. The tablets were much easier for SCUBA divers to handle and required far less equipment than was required for injecting liquid sodium hypochlorite. Use of chlorine necessitated obtaining a Research Authorization from Cal EPA/ DPR.

Containment and treatments of the largest colonies in Agua Hedionda began 17 days after the discovery of *C. taxifolia*. The rapid deployment of equipment and the associated treatments resulted from the fortuitous presence of a SCUBA team that was already working in the lagoon, and their commitment toward the eradication goal.

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Figure 3. Underwater containment and treatment system used to apply chlorine (liquid sodium hypochlorite) to colonies of *C. taxifolia* in Agua Hedionda Lagoon. 20 mil black PVC covers PVC frame. Fitting at top is port through which liquid sodium hypochlorite was pumped by SCUBA divers. (Photograph by L. Anderson.)

The subsequent discovery of *C. taxifollia* in the small embayments at Huntington Harbour, a few weeks after the find in Agua Hedionda, prompted similar containment, though only pvc tarps (without frames) and solid chlorine-releasing tablets were used since the colonies were smaller at this site.

Thus, from an operational perspective, expedient decisions were made based upon the need to act quickly and the desire to use those methods having reasonable probability for success, and which would be least likely to cause off-target concerns. Treatments were therefore confined to the known target 'volume'. The consensus was also that the dissipation of chlorine (dilution, breakdown and inactivation via particulate and dissolved organic matter) would likely be rapid.

An examination of the funding sources for this rapid response, and for continuing eradication actions during the past 3 years, reveals another unique aspect of the SCCAT consortium: the importance of individual efforts and personal commitments. The 'startup' emergency funds (about US$200,000) came from the San Diego Regional Water Quality Board and Cabrillo Power, LLC (a power plant located on the lagoon). Through the highly focused efforts of an Environmental Specialist on the San Diego Regional Water Quality Control Board, the invasion of *C. taxifolia* was treated like an oil spill, and thus qualified for emergency funding. As a result, US$100,000 became available almost immediately from emergency spill funding sources normally earmarked for 'clean up and abatement'. This example of creative and flexible thinking, coupled with personal dedication, represents the best qualities in regulatory scientists and managers.

The designation as a 'clean up and abatement action' also cleared potentially delaying legal constraints. The Board was able to issue required permits for the project, and CalEPA/DPR placed a high priority on issuance of authorization for use of chlorine. Similarly, when the Huntington Harbour infestation was found, the Santa Ana Regional Water Quality Control Board provided emergency funds for eradication there. The financial commitment from managers and staff at Cabrillo Power, LLC made the initial full treatments of the infestations possible and also served as a firm testament to the importance of achieving successful eradication.

Additional funding eventually followed from NOAA-Fisheries, California Department of Fish and Game (CDFG), and several subsequent grants that were tied to environmental coastal protection goals. Most recently, the California Coastal Conservancy has awarded US$1.3 million for the next year's (2004) eradication and monitoring efforts. However, due to the 'virtual' status of SCCAT, funds are either channeled directly to the operations contractor, or through the Agua Hedionda Laguna Foundation. SCCAT has served in an advisory, coordinating and reviewing capacity in the eradication efforts. (Appendix 1 summarizes the sources of funds to 2003 that also support public education and outreach, as well as research targeted to specific needs for eradication and detection)

Oversight and quality assurance

The very high profile nature of this project has attracted national and international interest (Dalton 2000, 2001). In fact, shortly after the eradication treatments began, a BBC film crew flew to San Diego expressly to include this work in a special documentary on the spread of *C. taxifolia* in the Mediterranean area. At the same time, the aggressive, eradication-only stance taken by SCCAT, coupled with high anticipated costs (ca.

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$1.2 million per year), provided plenty of fodder early on for second-guessing, and for continuing debates about what type of studies could have or should have been performed in the field short of contain and kill actions. The sources of these concerns derived from: (a) the reality and exigency of responding to a new invasive species with a clear history of detrimental, rapid spread (i.e., the Mediterranean coasts), and (b) divergent perspectives and priorities of scientists experienced with on-the-ground control and eradication approaches compared to the perspectives of their phycologist colleagues who, understandably, wanted the opportunity to investigate this 'new species' *in situ*. Finally, the lack of any recognizable track record of successfully eradicating *C. taxifolia* led some scientist to believe that it could not be done. This prompted discussion of the merits of first studying how it would grow here. Given these circumstances, together with the fact the *Caulerpa* genus, including C. *taxifolia*, comprise some of the most widely sold and shared tropical seawater plants for aquarium enthusiasts, it is no surprise that controversy developed. In addition, highly selective reporting in some media focused on controversial issues, rather than on the significant progress being made by SCCAT (e.g., Dalton 2000, 2001).

Efficacy of treatments

To develop quality assurance information and to evaluate the efficacy of the tarping and chlorine treatments, a series of sediment samples were taken from beneath the treated/tarped areas in December 2001, and August 2002. The hiatus between initial treatment and assessment was quite purposeful: The Technical Committee within SCCAT reasoned that risks associated with removing tarps and disturbing sediments too soon overrode the desirability of examining the treated plants, especially since the colonies were still well contained under the tarps. By December, 2001, SCCAT felt that adequate time had passed; therefore, following careful removal of sediments using pvc coring tubes, replicated 10 cm dia. by 20 cm deep samples were removed and transported to the USDA-ARS research facility on the UC Davis campus and placed in conditions that would promote growth of viable fronds or stolons. As a control for this procedure, other cores from similar sediments in uninfested and untreated areas were removed and inoculated with fronds of *C. taxifolia*: these cores supported continued growth from the fronds. However, in core samples taken inside treated areas from both sampling periods, December and August, no *C. taxifolia* emerged, nor were any intact pieces found 76 and 108 days after planting, respectively. Surprisingly, seedling eelgrass (*Zostera marina*) emerged from several cores from areas that had been previously covered and treated, and some living invertebrates were also present (Anderson 2002, 2003). These assays, therefore, indicated that treatments were successful in killing *C. taxifolia* and that, at least within the samples taken; other organisms survived the treatments, including seed of native eelgrass. Some of these cores were from sites that had been tarped and treated 2 years previously. Further examination of chlorine effects (e.g., dose/response) on *C. taxifolia* is underway (Williams and Schroeder 2003). Additional field assessments are also on going, including removal of small, replicated sections of tarps and monitoring of organisms that re-occupy these areas.

Program review

In order to assess the eradication progress, and to provide a forum for information exchange, the University of California Cooperative Extension hosted an International Conference on *C. taxifolia* at the end of January 2001 in San Diego, 50 km south of the original infestation (California Sea Grant 2002). Experts in *Caulerpa* taxonomy and ecology participated, including scientists from France, Italy, Croatia, and some Australian managers who were just beginning to react to a new *C. taxifolia* infestation. SCCAT was able to report that the first assessments of chlorine-treated areas indicated no potential for re-growth based on bioassay grow-out of sediment cores removed from beneath the tarps (Anderson 2002). Immediately following the conference, a Scientific Review Panel, requested by CDFG, reviewed the SCCAT actions and provided recommendations. Within the 17 recommendations, were several reasonable suggestions, such as: maintaining rapid response capacity (within

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30 days after new discovery), defining a lead agency, expanding surveillance in California, conducting risk assessment (for other potential infestation sites), conducting a review of project action protocols, and further investigation of methods to eradicate *C. taxifolia* and other invasive marine algae. However, the panel was divided on whether eradication was possible. For example, when polled as to the likelihood of successful eradication, 6 of the 11 Panel members felt there was less than a 50% probability; whereas five members ranked the chances around 80% (California Department of Fish and Game 2002).

Field monitoring for new growth

As the need for new containment and treatments declined by the end of the second season (fall 2002), the primary task shifted to monitoring for new growth within the Agua Hedionda Lagoon and Huntington Harbour sites. The usual criterion for eradication is quite simple: no living parts can remain to re-infest the site. This may seem trivial, yet searching under water for small, centimeter-sized pieces of fronds is very difficult due to poor visibility, tidal currents, epiphytic growth that can camouflage the plants, and the presence of other macrophytes such as eelgrass (*Z. marina*) that can occlude the divers' view. To accomplish the searches, teams of several divers follow prescribed transect lines laid with GPS units. The search grid provides approximately 1-meter spacing between lines so that some overlap occurs to minimize the chances of missing plants. Survey of the inner lagoon site at Agua Hedionda Lagoon takes approximately 5–7 days to complete, assuming favorable visibility. The search strategy has recently shifted to fewer surveys per year (now one spring and one fall search starting in fall 2003), and more defined search areas based upon historic 'discovery' patterns. Surveys of Huntington Harbour require less time due to the smaller area and generally higher frequency of conditions offering better visibility. Figure 4 shows that from an initial total infestation in Agua Hedionda Lagoon of about 1000 m^2 (June/July 2000), the area containing new plants declined dramatically during 2001–2002. A similar level of success has been achieved in Huntington Harbour. In fact, to date (July 2004) no new plants have been found in Agua Hedionda Lagoon since September 2002 or in Huntington Harbour since November 2002. This pattern of reduction is typical for eradication efforts, wherein dramatic reductions may be expected initially, followed by a diminished rate of reduction due to the difficulty in detection of smaller plants or colonies.

Given the increasing challenge of finding small plants, how does one know with some certainty that a zero-detection survey is not simply 'missed' plants? There are really three components to this question: (1) What are the divers' efficiency and ability to locate *C. taxifolia*? (2) What is the minimum size a colony has to attain to assure it will be detected 100% of the time in a standard search effort, and (3) conservatively, how long does it take for the plant to reach a minimum threshold size for assured detection? Part of the 2002/2003 surveys and monitoring efforts have addressed these questions by using ersatz (plastic) caulerpa fronds fastened together to produce 'colonies' of various sizes. In fact, the general efficiency (quality assurance) is now routinely determined by placements of the ersatz targets in locations not known to the search team. The "percent find" for single passes on the transect lines and can range from 30 to 80% depending primarily upon turbidity (clarity) of the water. The minimum size for 100% detection is presently being confirmed using four size ranges of the plastic caulerpa. Once this is known with reasonable certainty, then SCCAT will propose a final eradication timetable. The full set of criteria for establishing this schedule will first be submitted for technical, scientific review by the oversight committee that met in San Diego in January 2001. After review and consideration of comments, an Eradication Schedule (i.e. projected time to declare complete eradication) will be submitted to all stakeholders.

The SCCAT model

A summary of the events leading to the present stage in the SCCAT response is provided in Figure 5. Importantly, 'pre-conditions' were in place at the time the discovery was made. Even though

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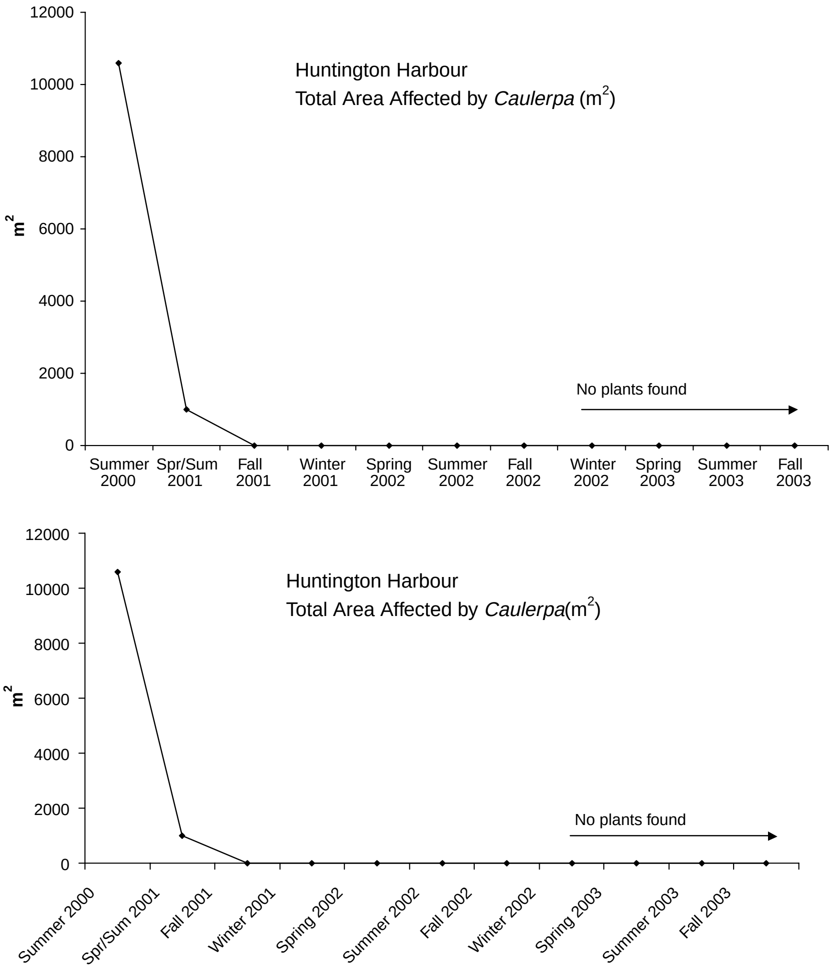

Figure 4. Progress in reduction in areal coverage of viable colonies of *C. taxifolia* over the past 3 years in Agua Hedionda Lagoon (upper graph) and Huntington Harbour (lower graph). Arrows indicate period of time during which no new colonies have been found. (Modified from Merkel and Associates, 2003 Status Report to SCCAT.)

there was no contingency fund in place, nor any team in place, the level of awareness of the threat from *C. taxifolia* had been well established, at least within a small circle of aquatic invasive species scientists and managers (Keppner et al. 1998; Keppner and Caplen 1999). This heightened awareness probably shaved weeks to months from on-the-ground response time. With fortuitous timing, Alex Meinesz's (1999) warning tome describing the consequences of no action against this species in Europe, was published shortly before the California discovery, and underscored the need to act quickly.

Though the SCCAT approach to the *C. taxifolia* infestation is not fundamentally different from many schemes proposed for rapid response, there are some assumptions in these schemes that probably should be modified based upon the SCCAT model. First, rather than a complex, nationally-centralized structure, I believe that the requirements for effective rapid responses can be distilled to three essential components that must be fully integrated at the local level: (1) biological and ecological knowledge of the invading species; (2) knowledge of the invaded site (physical, ecological, and sociological); (3) sufficient field expertise and resources for immediate action. By examining the functions of these components, one can understand how to prepare for the eventuality of a new introduction. Second, these com-

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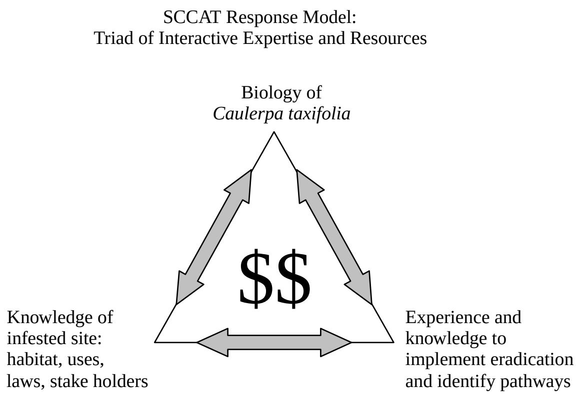

Figure 5. SCCAT Rapid Response Model showing the interactions of three essential components and mandatory funding to implement responses, with fully integrated information among the three input components.

ponents, taken separately, will not produce a coordinated, credible or effective response for a simple reason: The expertise within each functional component will only be productive in the context of the input from the other two. For example, phycologists may be knowledgeable about a given algal species and can provide crucial life cycle, reproductive and ecological information. However, without expertise in implementing a 'best eradication' option, or the knowledge of the infested site and pertinent sociological constraints, this biological information alone is not sufficient to develop a feasible strategy for eradication. The converse is of course true as well: scientists and managers versed in approaches and methods for containment, control and eradication may be ill prepared for using those tools without the relevant biological, regulatory, and stakeholder information. The need for this multidisciplinary consortium also suggests that the most effective participants will be those who truly understand their limitations, and who respect the expertise comprising the other components. This is a 'culture' that must be guided by common goals and a willingness to listen carefully to opposing views in order to develop a credible consensus for action. I believe that problems arising from some past reactions to invasive species derive directly from a failure to fully engage each of the three components at the onset of the response. Undoubtedly, SCCAT too would have benefitted from earlier, public informational stakeholder workshops. This is because the iterative, adaptive management approach that works best necessitates a series of meetings as new information is obtained and changes are proposed.

Third, whatever approach is taken in response to invasive species, adequate, accessible funding is absolutely essential. SCCAT was extremely fortunate in having a fully responsive agency, the San Diego Water Regional Water Control Board that had access to funds. This suggests that several state and federal agencies with resource management mandates must each be provided with a minimum of US $500,000 for rapid response. In addition, Memoranda of Understanding (MOUs) between state agencies, and between the states and the federal agencies, must prescribe how these funds can be transferred and shared quickly. The MOU for resource-sharing is equivalent to the practice of facilitating multi-city fire station coordination for responses to large fires.

Lastly, and this is probably the most important difference from other proposed schemes, the successful experiences with the California *H. verticillata* eradication program (California Department of Food and Agriculture 2003), with SCCAT, and with the less well-known sabellid (polychaete) worm eradication in the California abalone industry (Culver et al. 1997; Kuris and Culver 1999; Culver and Kuris 2000) all demonstrate that early and effective responses are locally driven (i.e., either impaired or facilitated), require key local stakeholders, and almost always need to engage local resources. In essence, this is a ''bottom-up'' model, which recognizes that vital information on infested sites, as well as public buy-in, must be achieved locally, and in the context of all available expertise and knowledge of the target species. The concept is summarized in Figure 5.

Assuming that the model can work, how could it be applied to other putative invasive species? The answer lies in part in the example of *C. taxifolia*'s status before it was discovered in the US (Figure 6). Rather than waiting for the first ''find'' in a new location, what is needed is a short list of likely invading species- either those yet to reach the US, or those localized in certain regions or states, but with clear potential to

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History of Response to *Caulerpa taxifolia* Invasion in the United States

Pre- Discovery Phase:	
1998	Aquatic Nuisance Species Task Force reviewed this threat
1999	*C. taxifolia* added to the Federal Noxious Weed List Draft of “Prevention Program for the Mediterranean Strain of *Caulerpa taxifolia*” submitted to the Aquatic Nuisance Species Task Force by Caulerpa Prevention Committee.
Post- Discovery Phase:	
June 12, 2000	*C. taxifolia* discovered in Agua Hedionda Lagoon, California
June 15, 18	Multi-Agency meetings held; confirmation of species ID, assessment of threat and options for response evaluated; consensus for action: <u>Eradicate</u>
June 29	<u>First eradication treatments begun.</u>
July, 2000	*C. taxifolia* discovered in Huntington Harbour, California Eradication treatments begun
July, 2001	Conference of “Implementing a National *Caulerpa taxifolia* Prevention Program”
September, 2001	State legislation to ban *C. taxifolia* and 8 other *Caulerpa* species signed by Governor
January, 2002	International Conference on *Caulerpa taxifolia* held in San Diego; Scientific Review Pan meets.
2001-2002	Efficacy assessments; containment and treatment of small colonies No new plants found by late, 2002.
2003-2004	Continued monitoring of both sites; criteria developed for declaration of full eradication

Figure 6. Summary of critical events in development of rapid response to *C. taxifolia* by the SCCAT.

spread and to damage aquatic resources. From this list, a ‘‘pest-alarm’’ drill, or exercise is run for each species in order to identify who (professionally and by agency and stakeholder group) will best provide expertise in the three rapid response components that I have described earlier. This telling exercise will quickly ferret out gaps in operational abilities (e.g., training needed, resources available), as well as identify likely pathways and sites of introduction. It will also identify scientists who are knowledgeable about the species' biology and those who are willing to be placed on standby. This will clarify ownership of likely infestation sites and help identify and resolve regulatory issues so that these do not impede timely action. Ideally, a species-specific response team could be designated and ready to act on a new discovery within a few days. Even if the new species is not from the original target list, most of the pre-infestation work will have been done anyway. Figure 7 summarizes a ‘pest alarm’ approach and suggests that these teams might be called a ‘NIPIT’, for Non-native Invasive Pest Intervention Team. I suggest that this alarm exercise might cost around US$5,000 per species, and that this up-front investment would reap tremendous return in shortening response time, providing effective use of resources and in elevating the public's awareness for the need to prevent establishment of these organisms. The recent report of yet another algal invasion, this time by *Caulerpa recemosa* in the Mediterranean Sea and Canary Islands (Verlaque, personal communication), suggests that this type of exercise and preparedness is urgently needed.

In summary, SCCAT has been extremely successful in spite of, and perhaps because of, the fact that no single agency federal, state, or local had both the authority and resources to implement actual eradication fieldwork. This circumstance required fluidity, flexibility and pragmatic decision-making. A collaborative culture was developed, wherein creative, adaptive problem solving has been the hallmark, and where the contributions of a wide range of public and private entities were essential. SCCAT continues to perform an effective role in facilitating and optimizing the use of resources to achieve the consensus goal: Eradication of *C. taxifolia* for the protection of California's coastal ecosystems.

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"Pest Alarm" Exercise:
An approach to identify expertise, resources and strategies
For Rapid Response to Invasive Aquatic species

Identify 3 to 5 likely "new invaders" based upon invasiveness, habitat, pathways
and probably sites of introduction

⇩

Treat each species separately, or as "like pest/pathways"
Start the Clock

⇩

Test the notification scheme: Who makes the calls? Who gets called?

⇩

Identify the pool of expertise: Who are they? What is their availability?

⇩

Identify informational gaps for targeted species and invaded site.

⇩

Who deals with news media?

⇩

Test the "Authority to Act": Agencies, Ownership, And Regulatory Constraints

⇩

Identify public and private stakeholders: How will they get engaged?
Who will organize them?

⇩

Identify organizational gaps, weak links and correct them.

⇩

Formalize a plan and develop an "Operational Manual" with clear
process diagrams and contact lists

⇩

Secure Access to Resources Needed (People, Equipment, Funding)

⇩

Action! Form "NIPITS": Non-native Invasive Pest Intervention Teams

Figure 7. Summary of 'Pest Alarm' exercise steps used to identify essential components for a rapid response to invasive species, and formation of operational non-native Invasive Species Intervention Teams, or 'NIPITS'.

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Appendix I
Sources of funding and approximate total amounts (US$) provided for *C. taxifolia* eradication from 2000–2003. (Note: Use of some funding extends to 2005.)

Contributing organization	Funds and other in-kind support
San Diego Regional Water Quality Control Board (via State Water Resources Control Board)	Designated *C.taxifolia* as 'pollutant' Approximately $2.0 million Provided for emergency 'cleanup' funding support; outreach and education.; research on high-energy habitat detection; participation by staff on SCCAT (SCCAT Chair/ Steering Committee)
Santa Ana Regional Water Quality Control Board (via State Water Resources Control Board)	Emergency clean up/abatement funds for Huntington Harbour infestation; approximately $700,000. Participation on SCCAT
California Department of Fish and Game	Directed funds of approximately $945,000. (Eradication, surveillance, research via UCD & ARS, outreach/education) Participation by staff on SCCAT (Steering Committee)
California Coastal Conservancy	Grant of $1.3 million for eradication/monitoring (via Agua Hedionda Lagoon Foundation)
California Department of Parks and Recreation	$15,000. Scientific Review process (via CDFG)
UC Davis/Research UC Davis/Extension	Phycological expertise; scientific support for improved eradication methods; research on chlorine efficacy; scientists Participation on SCCAT
US Department of Agriculture-Agricultural Research Service-Exotic and Invasive Weed Research	Scientific expertise in control and eradication of aquatic plants and algae; in-kind support for early assessment of algaecides and assessment of treatment efficacy; scientist participation on SCCAT (Steering Committee)
National Marine Fisheries Service (NOAA-Fisheries)	Approximately $300,000; Support to deal with Coastal Commission permits; staff scientist participation on SCCAT (Steering Committee)
US Fish and Wildlife Service (Coastal Program) and ANS Task Force	$212,000. for eradication/ surveillance (via NOAA-Fisheries); $40,000 (Scientific Review Panel)
Cabrillo Power, LLC	Early, rapid funding of ca. $123,000. to help support eradication; Participation on SCCAT
Merkel and Associates, Inc.	First detection and notification; contractor for operational, hands-on eradication field team; outreach/education; Participation on SCCAT
Agua Hedionda Lagoon Foundation	Public liaison and awareness; support for obtaining regulatory changes and funding; negotiations for adjusted Agua Hedionda Lagoon uses; obtained grants for eradication totaling approximately $2 million (310(h) funds and Ca.Coast.Comm.)
City of Carlsbad, CA	Security at Agua Hedionda Lagoon site; enforcement of boating restrictions; community outreach; staff participation on SCCAT

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